GR 6: Numerical relativity

Time: Wednesday 16:30–18:30 Location: H6

GR 6.1 Wed 16:30 H6

The rotating mass shell in general relativity — •Florian Atteneder[1], Tobias Benjamin Russ[2], Reinhard Alkofer[3], and Helios Sanchis-Alepuz[3] — [1]Theoretical Physics Institute, University of Jena, Jena, Germany — [2]Theoretical Physics, Ludwig Maxmillians University, Munich, Germany — [3]Institute of Physics, University of Graz, Graz, Austria

The model of a rotating mass shell (RMS) was initially introduced to judge if rotation has only relative meaning. It comprises a description of a spacetime with an energy-matter content that is assembled in a statically rotating quasi-spherical shell with zero radial extension. Latest perturbation theory (PT) calculations have shown that relativity of rotation is indeed realized in such a spacetime. However, because this conclusion was based on PT, its validity is limited to slowly RMSs. This work pursues a numerical treatment of the problem, where the mathematical formulation involves a splitting of the spacetime into a region that is flat and one that is asymptotically flat. The latter is used as a reference to define relative rotation. The RMS forms at the common boundary of these two regions. On the basis of previous work, we formulate Einstein's equations as a free-boundary value problem and solve them numerically using a pseudo-spectral method. As a result we obtain a three-parameter solution that is characterized by the shell's polar radius, its gravitational mass and angular momentum. The existence of the solution is enough to positively answer the question if Mach's idea of relativity of rotation can be extended for rapidly RMSs.

GR 6.2 Wed 16:45 H6

Hyperbolic-like Encounters of Binary Black Holes — •Hannes Rüter and Harald Pfeiffer — Albert Einstein Institute, Potsdam, Germany

We present results on the encounter of two black holes that are initially on a hyperbolic-like orbit simulated with the numerical relativity code SpEC. The two black holes either become bound due to the emission of gravitational waves or they escape to infinity. We present trajectories and waveforms for both cases and extract the scattering angle for the latter.

GR 6.3 Wed 17:00 H6

Prompt Collapse - The Effect of Mass Ratio — •Maximilian Kölsch[1], Tim Dietrich[2,3], Maximiliano Ujevic[4], and Bernd Brügmann[1] — [1]Theoretisch-Physikalisches Institut, FSU Jena — [2]Institut für Physik und Astronomie, Universität Potsdam — [3]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam — [4]Centro de Ciências Naturais e Humanas, Universidade Federal do ABC, Brazil, São Paulo

The outcome of a binary neutron star merger dominantly depends on the total mass of the system and the equation of state describing the matter. However, the mass ratio also influences the postmerger evolution, in particular, whether there is a prompt or delayed collapse. Furthermore, the mass ratio influences which fraction of the initial baryonic mass ends up in a disc around a so formed black hole, and the mass of the latter. We investigate with a new set of general relativistic simulations the prompt collapse threshold for various total masses, mass ratios, and three equations of state. We propose a fitting formula for the dependence of the threshold mass on the mass ratio.

GR 6.4 Wed 17:15 H6

Axisymmetric gravitational wave collapse with bamps. — •Sarah Renkhoff[1], David Hilditch[2], Daniela Cors Agulló[1], Isabel Suárez Fernández[2], and Bernd Brügmann[1] — [1]Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [2]CENTRA, University of Lisbon, 1049 Lisboa, Portugal

The new adaptive mesh refinement in our pseudospectral code bamps allows us to improve on previous results near the threshold of black hole formation. In particular, by leveraging the increased performance and scaling behaviour of the code, we can fine tune closer to the critical point between gravitational collapse and dispersed fields. We evolve six one-parameter families of Brill wave initial data: three prolate and three oblate, including two centred and four off-centred. Time permitting, we will discuss the relevance of our results in the context of critical collapse beyond spherical symmetry.

GR 6.5 Wed 17:30 H6

GR-Athena++: puncture evolutions on vertex-centered oct-tree AMR — •Francesco Zappa — Friedrich Schiller Universität, Jena, Germany

Numerical relativity is key to explore the strong-field gravity regime of black hole and compact binary systems. Multi-messenger astronomy requires accurate numerical relativity simulations in order to construct and develop precise gravitational-wave models and to study the outcome of black hole and neutron star mergers in regions of the parameter space which have not been explored yet. Such simulations can be very costly and thus highly performant and scalable codes, capable of efficiently using the modern massively-parallel architectures available nowadays, are needed.

We present GR-Athena++, an extension of the astrophysical code Athena++ which solves the Z4c equations to evolve the dynamical spacetime employing an oct-tree based adaptive mesh refinement strategy. We test our code comparing results from simulations of binary black hole mergers against other numerical relativity codes and performing comparisons against state-of-the-art effective-one-body waveforms. GR-Athena++ exhibits excellent scalability properties, inherited from Athena++ task-based parallelism strategy. Our tests show strong scaling efficiencies above 90% for up to $\sim 10^4$ CPUs and almost perfect weak scaling up to $\sim 10^5$ CPUs.

These results demonstrate that GR-Athena++ can perform accurate binary black hole evolution efficiently on a large number of CPUs, providing a viable option for exascale numerical relativity.

GR 6.6 Wed 17:45 H6

A discontinuous Galerkin elliptic solver with task-based parallelism for the SpECTRE code — •Nils Fischer — Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam, Germany

I present the solver for linear and nonlinear elliptic partial differential equations for SpECTRE, the next-generation numerical relativity code currently in development by the SXS collaboration. The solver combines nodal discontinuous Galerkin methods and task-based parallelism to target challenging elliptic problems in numerical relativity and beyond. In particular, I report on first results solving for black-hole binary and neutron-star binary initial data using our new numerical technology and I demonstrate the code's ability to scale to the capacity of the Minerva supercomputer at AEI Potsdam.

GR 6.7 Wed 18:00 H6

Long term simulations of magnetic fields in isolated neutron stars — •William Cook[1], Ankan Sur[2], Brynmor Haskell[2], David Radice[3,4,5], and Sebastiano Bernuzzi[1] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller Universitat Jena, 07743, Jena, Germany — [2]Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00-716 Warsaw, Poland — [3]Institute for Gravitation & the Cosmos, The Pennsylvania State University, University Park, PA 16802, USA — [4]Department of Physics, The Pennsylvania State University, University Park, PA 16802, USA — [5]Department of Astronomy & Astrophysics, The Pennsylvania State University, University Park, PA 16802, USA

We present the results of long term simulations of magnetised, isolated, neutron stars in the Cowling approximation, performed with the Athena++ code, lasting 490ms. By evolving neutron stars with initially poloidal and toroidal magnetic fields we investigate the long term development of the relative strengths of these components, as well as the onset of turbulent behaviour driven by an initial instability. We further investigate how the scaling of the energy spectrum evolves through the course of the simulation.

GR 6.8 Wed 18:15 H6

Binary neutron star merger simulations: ejecta, nucleosynthesis, EM counterparts — •Vsevolod Nedora — Theoretisch-Physikalisches Institut, Jena, Germany

GW170817 provided a plethora of information on binary neutron star (BNS) mergers and properties of matter at supranuclear densities. We further explore the remaining open questions with long-term numerical relativity (NR) BNS merger simulations with state-of-the-art numerical methods. Simulations include neutrino emission and reabsorption,

the magnetic field induced viscosity via an effective model, and microphysical equations of state (EOSs) with finite temperature effects.

We find that (i) post-merger evolution is accompanied by massive outflows, spiral-wave wind, driven by complex dynamical interaction between the remnant NS and the disk and finite temperature effects; (ii) the electromagnetic (EM) signature of this new outflow corresponds to the "blue" kilonova (kN); (iii) the rapid neutron capture, r-process, nucleosynthesis final abundances in total ejecta from our simulations are compatible with solar; (iv) non-thermal kN afterglow, emitted by the ejecta interacting with the interstellar medium is compatible with the recently observed change in GRB170817A afterglow.

Overall, our results highlight the importance of the ab-initio NR BNS merger simulations with microphysical EOSs and allow to place certain tentative constraints on the properties of GW170817 and, ultimately, NS EOS.